Multiwavelength Studies of Rotating Radio Transients

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Abstract. We describe our studies of the radio and high-energy properties of Rotating Radio Transients (RRATs). We find that the radio pulse intensity distributions are log-normal, with power-law tails evident in two cases. For the three RRATs with coverage over a wide range of frequency, the mean spectral index is -1.7 ± 0.1, roughly in the range of normal pulsars. We do not observe anomalous magnetar-like spectra for any RRATs. Our 94-ks *XMM-Newton* observation of the high magnetic field RRAT J1819−1458 reveals a blackbody spectrum (kT $\sim$ 130 eV) with an unusual absorption feature at $\sim$1 keV. We find no evidence for X-ray bursts or other X-ray variability. We performed a correlation analysis of the X-ray photons with radio pulses detected in concurrent observations with the Green Bank, Effelsberg, and Parkes telescopes. We find no evidence for any correlations between radio pulse emission and X-ray photons, perhaps suggesting that sporadicity is not due to variations in magnetospheric particle density but to changes in beaming or coherence.

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INTRODUCTION

Rotating Radio Transients (RRATs) were discovered through a reanalysis of archival data from the Parkes Multibeam Pulsar Survey (PMPS) [1]. Over 30 RRATs have been discovered since that time [2, 3, 4, 5, 6] Their transient nature implies a large Galactic RRAT population, most likely outnumbering the population of normal Galactic pulsars. Unless the populations are evolutionarily related, the implied neutron star (NS) birthrate may be inconsistent with the measured Galactic supernova rate [7]. In Figure 1, we compare the spin-down properties of the RRATs and other NSs. In general, RRATs have larger periods and magnetic fields than normal pulsars [9]. Some may be dying or extreme nulling pulsars [11] or simply normal radio pulsars for which we only see the bright tail of an extended pulse amplitude distribution [12]. An intriguing possibility is that their sporadicity is due to modulation from a radiation belt [13] or asteroid belt [14, 15]. It is also possible that some RRATs are transient X-ray magnetars. An unusual glitch detected from RRAT J1819−1458 suggests that it is transitioning from the magnetar to pulsar region of the $P-\dot{P}$ diagram [10]. Furthermore, *Chandra* observations revealed

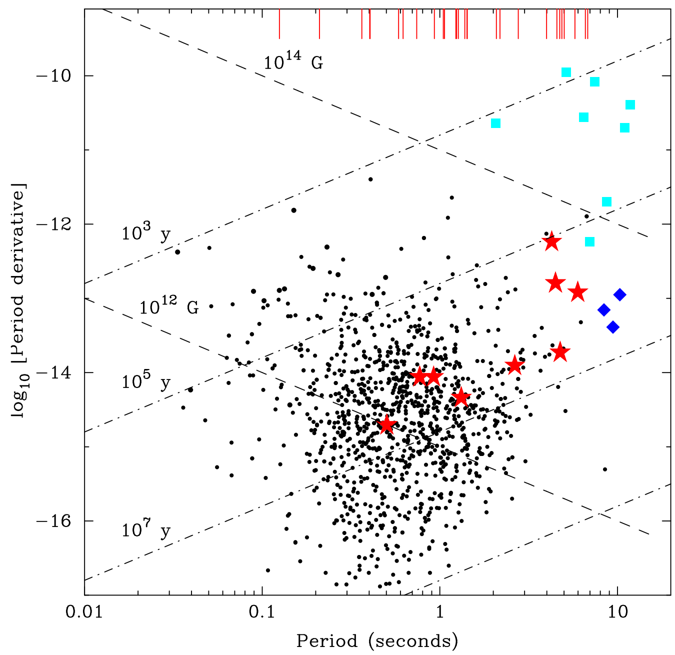

FIGURE 1. P-$\dot{P}$ diagram for RRATs (red stars), normal pulsars (black dots), magnetars (cyan squares), and X-ray-detected isolated neutron stars (blue diamonds). The $\dot{P}$ values are for eight Parkes RRATs ([9], [10], [8]) and one unpublished source from the 350-MHz GBT survey [8]. Dashed lines indicate constant characteristic age and constant inferred surface dipole magnetic field strength. Red lines at the top show the periods of the RRATs which do not yet have measured period derivatives.

an unusual pulsar wind nebula that is impossible to power through spin-down energy alone, suggesting a possible magnetic origin [16]. Finally, the spin-down properties of two of the RRATs place them in a region of $P-\dot{P}$ space devoid of pulsars and close to that occupied by INSs, suggesting another possible relationship.

Pulse Amplitude Distributions and Spectra

The pulse amplitude distributions of eight Parkes RRATs are well described by log-normal probability distribution functions, with two exceptions where a power-law tail is also required. Log-normal distributions are typical of pulsar single-pulse amplitude distributions [17], while the power-law tails are similar to those seen for giant-pulsing pulsars and, perhaps, magnetars [18, 19]. Observations at three to six radio frequencies allow us to calculate radio spectra for the RRATs. Fitting their pulse amplitude distributions, we find that the fluxes follow a power-law with frequency, like normal pulsars. For the three RRATs with observations over a wide-range (>1 GHz) of frequencies, the mean spectral index is -1.7 ± 0.1, consistent with those of normal pulsars. Our observations rule out flat spectra as seen for radio-emitting magnetars [20, 21, 23].

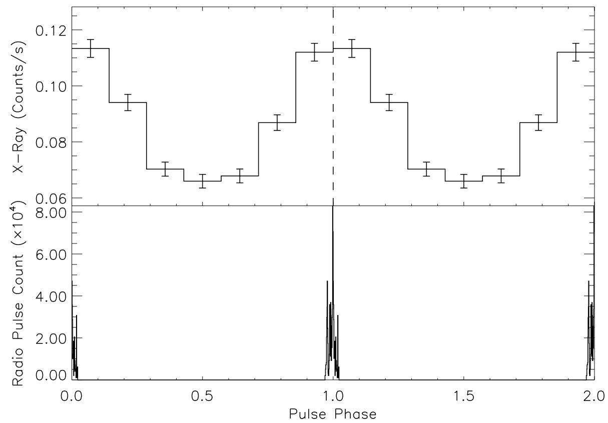

FIGURE 2. X-ray and radio profiles of J1819−1458 folded using the radio ephemeris. *Top:* X-ray profile consisting of seven phase bins for each rotational period and including photons with energies 0.5 keV $< E <$ 2.4 keV. The dotted line indicates the peak of the radio profile. *Bottom:* Histogram of the radio pulse arrival times. The profile is shown twice for clarity.

X-ray properties

We observed the high magnetic-field RRAT J1819−1458 with *XMM-Newton* for 94 ks on 31 March 2008. These data were taken with the EPIC-PN in Full Frame mode, and the two MOS with the central CCD in Small Window mode. Our time resolution of 73.4 ms is sufficient for studying the pulse profile. Restricting the energy range to 0.5 keV $< E <$ 2.4 keV, we fit the spectrum well with an absorbed blackbody with temperature of 128 ± 6 eV and a cyclotron absorption line at 1.07 ± 8 eV. We can not find a good fit for the blackbody spectrum alone. Coupled with the detection of this line in previous *XMM-Newton* observations [24] and *Chandra* data [16], we are certain of its astrophysical nature. If the line is due to proton resonant cyclotron scattering, this implies a magnetic field strength of 2×10^{14} G, four times as high as that measured from spin-down. Assuming an angle between the magnetic and spin axes of 15 degrees would make the spin-down magnetic field consistent with the cyclotron estimate. Note that while the cyclotron interpretation for the line is appealing, we are also not able to rule out an atmospheric absorption line. More careful spectral modeling and a phase-resolved analysis is required to conclusively determine the nature of the line.

X-ray and radio correlation analysis

We observed J1819−1458 with the GBT, Parkes, and Effelsberg radio telescopes at frequencies of 2, 1.4, and 1.4 GHz, respectively, concurrently with the 94-ks *XMM-Newton* observation. We detected 6800 X-ray photons (in the energy range 0.5 keV $< E <$ 2.4 keV) and 931 radio pulses (165 from Parkes over ∼9 hours, 64 from Effelsberg over ∼5 hours, and 673 from the GBT over ∼7 hours). In Figure 2,

we present the X-ray profile and the profile of the radio bursts. The two profiles align, with the X-ray profile well-described by a sinusoid (as would be expected from thermal emission).

We searched for correlations between the radio pulses and X-ray photons by calculating the number arriving within some time window of each other and then repeating this analysis for simulated randomly distributed pulses. We find no evidence for any excess X-ray emission at the times of the radio pulses on timescales from one pulse period. This may imply that the RRAT radio sporadicity is due to beaming or radio coherence and not due to an increase in particle density in the magnetosphere, which might be expected to heat the polar cap and lead to increased X-ray emission [11].

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